United States Patent Application for:

GAS DELIVERY SYSTEM FOR SEMICONDUCTOR PROCESSING

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Applied Docket No:	007728 USAP01/DSM/HDP/CVD/JW
J&A Docket No:	7728.P1/GSDT

Express Mail Mailing Label No: EV341109456US Date of Deposit: April 16, 2004

GAS DELIVERY SYSTEM FOR SEMICONDUCTOR PROCESSING

CROSS-REFERENCES

This application is a continuation-in-part of U.S. Patent Application No. 10/630,989, entitled "Gas Delivery System for Semiconductor Processing," to Gondhalekar et al., filed on July 28, 2003, which is based on and claims the benefit of U.S. Provisional Patent Application No. 60/410,353, entitled "Gas Delivery System for Semiconductor Processing," to Gondhalekar et al., filed on September 13, 2002. Both of these applications are incorporated herein by reference in their entirety.

BACKGROUND

This invention relates generally to a gas delivery system for semiconductor processing.

The fabrication of integrated circuits (ICs) involves performing a number of processes on a substrate in a process chamber, including the deposition of layers on the substrate, etching of gaps in the substrate, and filling of the gaps. The process chamber typically comprises a gas distributor having nozzles extending into the chamber, a gas energizer, and an exhaust port to remove the gas. The gas energizer may include electrodes to which a bias power is applied or an antenna to which a source power is applied. Periodically, between each substrate processing cycle, the internal surfaces of the chambers are cleaned in a cleaning process to remove accumulated process residues that form on the chamber components and surfaces.

Chemical vapor deposition (CVD) is a gas process used in the semiconductor industry to deposit material on a substrate. Some high density plasma (HDP) enhanced CVD processes use a gas along with ion generation through the use of a high frequency generated plasma, such as an RF plasma, to enhance deposition by attraction of the positively charged plasma ions onto a negatively biased substrate surface at angles near the vertical to the surface, or at preferred angles to the surface by directional biasing of the substrate surface. The high RF power HDP-CVD process results in improved gapfill, particularly for gaps having a width of equal to or less than about 90 nm and an aspect ratio of at least about 4. For example, the source RF power

is at least about 10 kW for processing 200 mm substrates and the source RF power is at least about 12 kW for processing 300 mm substrates.

However, the higher RF powers used for gap filling in CVD processes, can increase particle generation in the chamber. This occurs because the plasma species having increased energy impinge upon and cause flaking of the accumulated deposits from internal surfaces in the chamber, particularly from the nozzles of a gas distributor. The flaked particles land on the substrate and reduce its yields. Cleaning the chamber surfaces by a plasma cleaning process that is performed after the processing of every substrate, can reduce the accumulation of the process residues, and thereby provide better yields. However, this extra cleaning step between each process cycle results in a lot of chamber downtime, which undesirably increases capitalization costs.

Thus, it is desirable to have a process chamber capable of accepting higher RF powers in processes, such as CVD processes. It is also desirable to have a gas distributor that does not generate excessive residues in the chamber. It is further desirable to maximize the number of substrate process cycles between each cleaning cycle to more efficiently utilize the chamber.

SUMMARY

A replaceable gas nozzle is insertable in a gas distributor ring of a substrate processing chamber and can be shielded within the chamber. The replaceable gas nozzle has a longitudinal ceramic body having a channel to direct the flow of the gas into the chamber. The ceramic body includes a first external thread to mate with the gas distributor ring, and a second external thread to receive a heat shield. The channel has an inlet to receive the gas from the gas distributor ring and a pinhole outlet to release the gas into the chamber.

In another embodiment, a heat shield is also provided for shielding the nozzle extending into the chamber. The heat shield has a hollow member configured to be coupled with the nozzle. The hollow member has an internal dimension sufficiently large to be disposed around at least a portion of the nozzle. The hollow member also has an extension which projects distally of the outlet of the nozzle and a heat shield opening for the process gas to flow therethrough from the nozzle outlet.

DRAWINGS

Fig. 1 is a simplified diagram of an exemplary embodiment of a high density plasma chemical vapor deposition (HDP-CVD) system;

Fig. 2 is a simplified cross section of a gas distributor ring that may be used in conjunction with the exemplary HDP-CVD system of Fig. 1;

Fig. 3 is a cross-sectional view of an embodiment of a nozzle;

Figs. 4a,b are partial cross-sectional views of an embodiment of a nozzle and a heat shield; and

Fig. 5 is a graph showing plots of the number of generated particles over processing time that compares the experimental results of a CVD system that is absent heat shields for the nozzles and a CVD system having heat shields about the nozzles.

DESCRIPTION

Fig. 1 illustrates an embodiment of a high density plasma chemical vapor deposition, such as a HDP-CVD type system 10, in which a dielectric layer can be deposited on a substrate. The system 10 includes a chamber 13, a vacuum system 70, a source plasma system 80A, a bias plasma system 80B, a gas delivery system 33, and a remote plasma cleaning system 50. The upper portion of chamber 13 has a ceiling 14 that can be a straight wall or a dome shape, which is made of a ceramic material, such as, aluminum oxide, silicon oxide or aluminum nitride, or a metal, such as aluminum. The ceiling 14 defines an upper boundary of a plasma processing region 16. Plasma processing region 16 is bounded on the bottom by the upper surface of a substrate 17 and a substrate support 18.

A heater plate 23 and a cold plate 24 surmount, and are thermally coupled to, ceiling 14. Heater plate 23 and cold plate 24 allow control of the ceiling temperature to within about ± 10°C over a range of about 100°C to about 200°C. This allows optimizing the ceiling temperature for the various processes. For example, it may be desirable to maintain the ceiling at a higher temperature for cleaning or etching processes than for deposition processes. Accurate control of the ceiling temperature also reduces the flake or particle counts in the chamber and improves adhesion between the deposited layer and the substrate.

Generally, exposure to the plasma heats a substrate positioned on substrate support 18. Substrate support 18 includes inner and outer passages (not shown) that can deliver a heat transfer gas (sometimes referred to as a backside cooling gas) to the backside of the substrate.

The lower portion of chamber 13 includes a body member 22, which joins the chamber to the vacuum system. A base portion 21 of substrate support 18 is mounted on, and forms a continuous inner surface with, body member 22. Substrates are transferred into and out of chamber 13 by a robot blade (not shown) through an insertion/removal opening (not shown) in the side of chamber 13. Lift pins (not shown) are raised and then lowered under the control of a motor (also not shown) to move the substrate from the robot blade at an upper loading position 57 to a lower processing position 56 in which the substrate is placed on a substrate receiving portion 19 of substrate support 18. Substrate receiving portion 19 includes an electrostatic chuck 20

that secures the substrate to substrate support 18 during substrate processing. In a preferred embodiment, substrate support 18 is made from an aluminum oxide or aluminum ceramic material.

Vacuum system 70 includes throttle body 25, which houses three-blade throttle valve 26 and is attached to gate valve 27 and turbo-molecular pump 28. It should be noted that throttle body 25 offers minimum obstruction to gas flow, and allows symmetric pumping, as described in co-pending, co-assigned U.S. Patent Application No. 08/574,839, filed December 12, 1995, and which is incorporated herein by reference. Gate valve 27 can isolate pump 28 from throttle body 25, and can also control chamber pressure by restricting the exhaust flow capacity when throttle valve 26 is fully open. The arrangement of the throttle valve, gate valve, and turbo-molecular pump allow accurate and stable control of chamber pressures from between about 1 milli-Torr to about 2 Torr.

The source plasma system 80A includes a top coil 29 and side coil 30, mounted on ceiling 14. A symmetrical ground shield (not shown) reduces electrical coupling between the coils. Top coil 29 is powered by top source RF (SRF) generator 31A, whereas side coil 30 is powered by side SRF generator 31B, allowing independent power levels and frequencies of operation for each coil. This dual coil system allows control of the radial ion density in chamber 13, thereby improving plasma uniformity. Side coil 30 and top coil 29 are typically inductively driven, which does not require a complimentary electrode. In a specific embodiment, the top source RF generator 31A provides up to about 8,000 watts of RF power or higher at nominally 2 MHz and the side source RF generator 31B provides up to 8,000 watts of RF power or higher at nominally 2 MHz. The operating frequencies of the top and side RF generators may be offset from the nominal operating frequency (e.g. to 1.7–1.9 MHz and 1.9–2.1 MHz, respectively) to improve plasma-generation efficiency.

A bias plasma system 80B includes a bias RF (BRF) generator 31C and a bias matching network 32C. The bias plasma system 80B capacitively couples substrate portion 17 to body member 22, which act as complimentary electrodes. The bias plasma system 80B serves to enhance the transport of plasma species (e.g., ions) created by the source plasma system 80A to the surface of the substrate. In a specific embodiment, bias RF generator provides up to 8,000 watts of RF power or higher at 13.56 MHz.

RF generators 31A and 31B include digitally controlled synthesizers and operate over a frequency range between about 1.8 to about 2.1 MHz. Each generator includes an RF control circuit (not shown) that measures reflected power from the chamber and coil back to the generator and adjusts the frequency of operation to obtain the lowest reflected power, as understood by a person of ordinary skill in the art. RF generators are typically designed to operate into a load with a characteristic impedance of 50 ohms. RF power may be reflected from loads that have a different characteristic impedance than the generator. This can reduce power transferred to the load. Additionally, power reflected from the load back to the generator may overload and damage the generator. Because the impedance of a plasma may range from less than 5 ohms to over 900 ohms, depending on the plasma ion density, among other factors, and because reflected power may be a function of frequency, adjusting the generator frequency according to the reflected power increases the power transferred from the RF generator to the plasma and protects the generator. Another way to reduce reflected power and improve efficiency is with a matching network.

Matching networks 32A and 32B match the output impedance of generators 31A and 31B with their respective coils 29 and 30. The RF control circuit may tune both matching networks by changing the value of capacitors within the matching networks to match the generator to the load as the load changes. The RF control circuit may tune a matching network when the power reflected from the load back to the generator exceeds a certain limit. One way to provide a constant match, and effectively disable the RF control circuit from tuning the matching network, is to set the reflected power limit above any expected value of reflected power. This may help stabilize a plasma under some conditions by holding the matching network constant at its most recent condition. Other measures may also help stabilize a plasma. For example, the RF control circuit can be used to determine the power delivered to the load (plasma) and may increase or decrease the generator output power to keep the delivered power substantially constant during deposition of a layer.

A gas delivery system 33 provides gases from several sources 34A-34F to the chamber for processing the substrate via gas delivery lines 38 (only some of which are shown). Gases delivered by the gas delivery system 33 can include, for example, silane, helium, and oxygen, which are used, for example, in the deposition of a silicon dioxide film. As would be understood by a person of skill in the art, the actual sources used for sources 34A-34F and the actual connection of delivery lines 38 to

chamber 13 varies depending on the deposition and cleaning processes executed within chamber 13. Gases are introduced into chamber 13 through a gas distributor ring 37 and/or a top nozzle 45. Fig. 2 is a simplified, partial cross-sectional view of chamber 13 showing additional details of gas distributor ring 37.

In one embodiment, first and second gas sources, 34A and 34B, and first and second gas flow controllers, 35A' and 35B', provide gas to ring plenum 36 in gas distributor ring 37 via gas delivery lines 38 (only some of which are shown). Gas distributor ring 37 has a plurality of gas nozzles 39A (only one of which is shown for purposes of illustration) that provides a uniform flow of gas over the substrate. Nozzle length and nozzle angle may be changed to allow tailoring of the uniformity profile and gas utilization efficiency for a particular process within an individual chamber. In one embodiment, gas distributor ring 37 has 24 gas nozzles 39A made from an aluminum oxide ceramic.

Gas distributor ring 37 also has a plurality of gas nozzles 39B (only one of which is shown), which in a preferred embodiment are co-planar with and the same in length as source gas nozzles 39A, and in one embodiment receive gas from body plenum 41. Gas nozzles 39A and 39B are not fluidly coupled in some embodiments where it is desirable not to mix gases before injecting the gases into chamber 13. In other embodiments, gases may be mixed prior to injecting the gases into chamber 13 by providing apertures (not shown) between body plenum 41 and gas distributor ring plenum 36. In one embodiment, third and fourth gas sources, 34C and 34D, and third and fourth gas flow controllers, 35C' and 35D', provide gas to body plenum via gas delivery lines 38. Additional valves, such as 43B (other valves not shown), may shut off gas from the flow controllers to the chamber.

In embodiments where flammable, toxic, or corrosive gases are used, it may be desirable to eliminate gas remaining in the gas delivery lines after a deposition. This may be accomplished using a 3-way valve, such as valve 43B, to isolate chamber 13 from delivery line 38A and to vent delivery line 38A to vacuum foreline 44, for example. As shown in Fig. 1, other similar valves, such as 43A and 43C, may be incorporated on other gas delivery lines. Such 3-way valves may be placed as close to chamber 13 as practical, to minimize the volume of the unvented gas delivery line (between the 3-way valve and the chamber). Additionally, two-way (on-off) valves (not

shown) may be placed between a mass flow controller ("MFC") and the chamber or between a gas source and an MFC.

Referring again to Fig. 1, chamber 13 also has top nozzle 45 and top vent 46. Top nozzle 45 and top vent 46 allow independent control of top and side flows of the gases, which improves film uniformity and allows fine adjustment of the film's deposition and doping parameters. Top vent 46 is an annular opening around top nozzle 45. In one embodiment, first gas source 34A supplies source gas nozzles 39 and top nozzle 45. Source nozzle MFC 35A' controls the amount of gas delivered to source gas nozzles 39 and top nozzle MFC 35A controls the amount of gas delivered to top gas nozzle 45. Similarly, two MFCs 35B and 35B' may be used to control the flow of oxygen to both top vent 46 and oxidizer gas nozzles 39B from a single source of oxygen, such as source 34B. The gases supplied to top nozzle 45 and top vent 46 may be kept separate prior to flowing the gases into chamber 13, or the gases may be mixed in top plenum 48 before they flow into chamber 13. Separate sources of the same gas may be used to supply various portions of the chamber.

In the embodiment shown in Figs. 1 and 2, remote plasma cleaning system 50 is provided to periodically clean deposition residues from chamber components. The cleaning system includes a remote gas activator 51 that creates a plasma in reactor cavity 53 from a cleaning gas source 34E comprising, for example, molecular fluorine, nitrogen trifluoride, other fluorocarbons or equivalents. The reactor cavity 53 may comprise, for example, a toroidally or cylindrically shaped cavity. The remote gas activator 51 may comprise, for example, an inductive coil wrapped around the reactor cavity 53, or a microwave generator coupled to the reactor cavity 53. An example of a remote plasma cleaning system commercially available is the Xstream Remote Plasma Source from Advanced Energy Industries, Inc, in Fort Collins, Colorado. The reactive species resulting from this plasma are conveyed to chamber 13 through a cleaning gas feed port 54 via an applicator tube 55. For example, in one embodiment, the cleaning gas feed port 54 feeds into plenum 48 and the cleaning gas enters into the chamber 13 through top vent 46. However, in other embodiments, the cleaning gas feed port 54 may be separate from plenum 48 and top vent 46, feeding directly into chamber 13. The materials used to contain the cleaning plasma (e.g. cavity 53, and applicator tube 55) must be resistant to attack by the plasma. The distance between reactor cavity 53 and feed port 54 should be kept as short as practical, since the concentration of desirable plasma species may decline with

distance from reactor cavity 53. Generating the cleaning plasma in a remote cavity allows the use of an efficient remote gas activator 51 and does not subject chamber components to the temperature, radiation, or bombardment of the glow discharge that may be present in a plasma formed in situ. Consequently, relatively sensitive components, such as electrostatic chuck 20, do not need to be covered with a dummy wafer or otherwise protected, as may be required with an in situ plasma cleaning process.

System controller 60 controls the operation of system 10. System controller 60 includes a processor 61 coupled to a memory 62. Preferably, memory 62 may be a hard disk drive, but of course memory 62 may be other kinds of memory, such as ROM, PROM, and others. In another embodiment, controller 60 also includes a floppy disk drive (not shown) and a card rack (not shown). The card rack may contain a single-board computer (SBC) (not shown), analog and digital input/output boards (not shown), interface boards (not shown), and stepper motor controller boards (not shown).

System controller 60 operates under the control of a computer program stored on the hard disk drive or other computer programs, such as programs stored on a floppy disk. The computer program dictates, for example, the timing, mixture of gases, RF power levels and other parameters of a particular process. The interface between a user and the system controller is via a monitor (not shown), such as a cathode ray tube, and a light pen (not shown). The computer program code can be written in any conventional computer readable programming language such as 68000 assembly language, C, C++, or Pascal. Suitable program code is entered into a single file, or multiple files, using a conventional text editor, and stored or embodied in a computer-usable medium, such as a memory system of the computer. If the entered code text is in a high level language, the code is compiled, and the resultant compiler code is then linked with an object code of precompiled library routines. To execute the linked compiled object code, the system user invokes the object code, causing the computer system to load the code in memory, from which the CPU reads and executes the code to perform the tasks identified in the program.

Figure 3 shows a replaceable ceramic gas nozzle 39 that is used to provide gas flow over the substrate in the chamber. The gas nozzle 39 may be any one of the nozzles 39B, 39B shown in Fig. 2. The gas nozzle 39 comprises a longitudinal ceramic body 82. In one version, the ceramic body 82 is cylindrical. The nozzle 39 and

ceramic body 82 have a proximal end 83 and a distal end 85. The proximal end 83 of the ceramic body 82 is connected to the gas distributor ring 37 and the distal end 85 extends into the chamber 13.

The ceramic body 82 comprises a channel 84 to direct the flow of the gas into the chamber 13. The size of the channel 84 is selected to provide pressure and flow rate characteristics to the flow of gas. In one version, the channel cross-section is circular and has a symmetric diameter about the central axis of the channel. The axially centered channel 84 is sized by selecting the channel diameter. In one version, the channel diameter is about 1.1 mm to about 2.1 mm, or even about 1.5 mm to about 1.7mm. The distance the gas travels through the channel 84 corresponds to the total length of the nozzle 39. In one version, the length of the nozzle 39 is about 55 mm to about 67 mm, or even about 64 mm to about 66 mm, or even about 57 mm to about 59 mm.

The channel 84 comprises an inlet 86 to receive the gas from the gas distributor ring 37. The inlet 86 is located at the end of the channel 84 at the proximal end 83 of the ceramic body 82. The inlet 86 is an opening having a diameter sized to receive a gas flow from the gas distributor ring 37. The channel 84 may comprise a tapered inlet portion 87 near the inlet 86 that constricts the width of the gas flow from the diameter of the inlet 86 to the channel diameter. The inlet diameter and the length of the tapered inlet portion 87 of the channel 84 are selected to provide flow rate and pressure characteristics to the gas flow. For example, in one version, the inlet diameter can be about 2.5 to 3.5 mm, or even about 3.0 to 3.1 mm, and the tapered inlet portion 87 of the channel 84 over which the gas flow is constricted can be about 0.8 to 1.8 mm, or even about 1.2 to 1.4 mm.

The channel 84 comprises a pinhole outlet 90 through which one or more process gases flow into the chamber 13 at the distal end 85 of the ceramic body 82. The pinhole outlet 90 has a diameter d_o selected to provide gas flow rate and pressure characteristics to the flow of gas. In one version, the outlet diameter d_o may be about 0.3 mm to about 0.4 mm. The channel may also comprise an tapered outlet portion 92 that constricts the gas flow from the channel diameter to the pinhole outlet diameter d_o. The tapered outlet portion 92 provides a transition between the flow of the gas in the channel 84 and the flow of the gas out of the pinhole outlet 90 without adversely affecting the gas flow characteristics.

The proximal end 83 of the gas nozzle ceramic body 82 connects to the gas distributor ring 37. The ceramic body 82 comprises a first external thread 88 to mate with the gas distributor ring 37. The first external thread 88 is sized to provide convenient and hermetic assembly of the nozzle 39 to the gas distributor ring 37. In one version, the first external thread 88 is a UNF-2A (Unified National Fine, standard class, external thread) style thread, with about 0.9 to about 1.0 threads per mm, and about a 3.0 to 3.6 mm longitudinal section of the nozzle 39 threaded. The profile of the proximal end 83 of the ceramic body 82 may also be adapted to mate with the gas distributor ring 37. For example, the proximal end 83 may include surfaces or have a geometry that conformally mates with corresponding surfaces or geometry of a receiving portion of the gas distributor ring 37.

Due to the process environment, the nozzle 39 may experience unwanted deposition or degradation, and thus the nozzle 39 is designed to be replacable. For example, the nozzle 39 may be used to deliver etching or deposition gases to the chamber 13. These gases may further be activated by the source plasma system 80A or the bias plasma system 80B. Such gases may produce deposits on the nozzle 39 or etch the nozzle 39. Over time, dimensional features of the nozzle 39, such as the pinhole outlet diameter d_o, may become distorted from the original specifications. Such distortion may cause undesirable change in the characteristics of the gas flow from the nozzle 39. Thus, the nozzle 39 is designed to be replaceable. The first external thread 88 provides an interface between the gas nozzle 39 and the gas distributor ring 37 that allows replacement of the nozzle 39.

The ceramic body 82 comprises a distal end 85 projecting into the chamber 13. The distal end 85 of the nozzle 39 is subject to the temperature rise from the energy generated in the chamber 13. The distal end 85 of the nozzle 39 is typically tapered into a tip 93. The tapering of the distal end 85 contributes to producing a uniform flow of gas over the substrate from the nozzle outlet 90. For example, the distal end 85 of the nozzle 39 may taper at an angle of about 35 to 45° relative to a longitudinal central axis 94 of the channel 84 in the nozzle 39.

The nozzle body 82 comprises a second external thread 89 to receive a heat shield 91. The second external thread 89 is located proximally from the pinhole outlet 90 by a distance d_{st}. The distance d_{st} is selected to avoid impacting the characteristics of the flow of gas from the pinhole outlet 90. For example, the pinhole

outlet diameter d_o is selected to provide a pressure and flow rate to the gas flow exiting the nozzle 39 into the chamber 13. The presence of the second threaded connection 89 from the nozzle 39 to the heat shield 91 may adversely impact the fluid dynamics of the gas flow into the chamber 13. For instance, the heat shield 91 connected to the nozzle 39 at a location behind the pinhole outlet 90 may change the pressure gradient of gas external to the nozzle 39 in the spatial region from the pinhole outlet 90 to the second external thread 89, which may affect the gas flow characteristics from the pinhole outlet 90. For this reason, the distance d_{st} is selected to provide separation between the pinhole outlet 90 and the second external thread 89 to avoid adverse effects of the second external thread 89 on the pinhole outlet 90. In one version, the distance d_{st} is selected to be about 90 to about 140 times d_o. In another version, the distance d_{st} is selected to be about 30 mm to about 55 mm.

Figs. 4a, b show a heat shield 91 which can be used to shield the nozzle 39 from the heat generated in the CVD chamber 13 by plasma or other energy applied to perform a process in the CVD chamber 13. Due to the low thermal mass at the nozzle tip 93, the distal end 85 of the nozzle 39 typically experiences the greatest temperature rise due to the energy generated in the chamber 13. It is thus desirable to shield the portion of the nozzle 39 exposed inside the chamber 13, including the distal end 85 of the nozzle 39. As shown in Fig. 4a, b, the heat shield 91 is configured to be disposed around at least a portion of the nozzle 39, desirably around the entire portion of the nozzle 39 that is exposed in the chamber 13. The heat shield 91 as shown is a separate piece that is coupled to the nozzle 39. For example, the heat shield 91 can have an internal thread 97 to mate with the nozzle 39. Such a heat shield 91 can be conveniently retrofitted onto nozzles in existing CVD chambers. Separate heat shield and nozzle components also have the advantage of each item being separately replaceable. However, in other embodiments, the heat shield 91 may be formed integrally with the nozzle 39.

In the embodiment shown, the heat shield 91 has a hollow member 96 which has an internal dimension sufficiently large to be placed around the nozzle 39. In one version, the hollow member 96 is cylindrical. The internal cross-section of the heat shield 91 desirably is slightly larger than the external cross-section of the nozzle 39, as seen in Fig. 4. In the specific embodiment, the gap or spacing between the heat shield 91 and the nozzle 39 is smaller than the thickness of the heat shield 91. The heat shield 91 includes a heat shield opening 95 through which the process gas flows from

the nozzle pinhole outlet 90. The heat shield 91 preferably includes an extension 98 which projects distally of the nozzle pinhole outlet 90 at the distal end 85 of the nozzle 39. The length of the extension 98 should be sufficiently large to shield the distal end 85 of the nozzle 39 from the heat in the chamber 13. The length of the extension 98 should not be so large as to have an adverse effect on the process being performed, such as the uniformity of a layer being formed on the substrate 17. Moreover, an excessively long extension 98 may produce additional particles. In some embodiments, the length of the extension 98 is between the radius of the nozzle 39 and the diameter of the nozzle 39. In one version, the length of the extension 98 is about 5 mm to about 8 mm. In a specific embodiment, the length of the extension 98 is about 6.4 mm, the heat shield 91 has a length of about 50.0 mm, an outer diameter of about 16.1 mm, and a thickness of about 3.9 mm. As shown in Figs. 1 and 2, the nozzles 39A, 39B are disposed around the substrate support 18. Heat shields 91 may be placed around some or all of the nozzles 39A, 39B. In some embodiments, the nozzles 39 and heat shields 91 are configured such that the heat shield openings 95 are disposed radially outwardly of the periphery of the substrate 17. That is, if the heat shields 91 are projected vertically downward onto the plane of the substrate 17, the heat shields 91 do not overlap with the substrate 17.

Although the heat shield 91 as shown has a uniform circular cross-section with a uniform thickness, it is understood that other configurations, shapes, and thickness profiles may be employed in different embodiments.

The nozzle 39 and the heat shield 91 are typically composed of a ceramic material. Ceramic materials are a good choice because they are stable at high operating temperatures. In one version the nozzle 39 and heat shield 91 are composed of aluminum oxide. In another version, the nozzle 39 and heat shield 91 are composed of aluminum nitride. In some embodiments, the heat shield 91 and the nozzle 39 are made of the same material, such as aluminum oxide or aluminum nitride, however in other embodiments, the nozzle 39 and heat shield 91 can each be made of different materials. In other versions, the heat shield 91 and nozzle 39 can be made from alternative materials, for example, metals such as aluminum.

In one version, the nozzle 39 and heat shield 91 form a replaceable shielded gas nozzle 99. In this version, the shielded gas nozzle can be replaced as a single unit. This version is advantageous when the heat shield 91 and nozzle 39 have

dimensional relationships, for example, between d_0, d_{st}, and the length of the extension 98, that are suitable for a particular process being conducted in the chamber 13. Using and replacing the shielded gas nozzle 99 as a single unit preserves these dimensional relationships and thus increases the quality and reliability of the process conducted in the chamber 13.

The heat shield 91 keeps the nozzle temperature relatively low to provide improved particle performance. A source of particles for high power recipes in plasma CVD chambers has been identified by a combination of modeling and experiments to be particles generated due to silane (SiH4) pyrolysis that results from an increase in nozzle temperature in the plasma at high source RF power levels. This gas phase particle nucleation mechanism produces hydrogenated Si clusters (e.g., Si2H6) as well as SiO2 particles due to plasma oxidation. Particle SEM plots show spherical particles consistent with gas phase nucleation. The nozzles 39 and heat shields 91 decrease nozzle temperatures in the chamber 13 to impede the gas phase particle nucleation mechanism. Impeding the gas phase nucleation mechanism reduces particle generation, and thus reduces defects caused by particles falling on the substrate 17 being processed in the chamber 13.

The present invention is applicable to various processes including STI, IMD (inter-metal dielectric), PSG (phosphosilicate glass), FSG (fluosilicate glass), and the like. The lower operating temperatures of the heat shield 91 and nozzle 39 also allow operation at higher power levels in the plasma CVD chamber 13, for instance, for improved gapfill capability. In addition to improved gapfill, reduced particle generation allows the chamber 13 to be used for a longer time for processing substrates 17 before the chamber 13 needs to be cleaned. This is referred to as multi-x clean. For example, without the heat shield 91 and nozzle 39 of the current invention, a cleaning process may need to be run after processing of a single substrate 17. With the reduced particle generation of the heat shield 91 and nozzle 39, for example, 2 to 5 substrates 17 can be processed with CVD deposition before a cleaning process needs to be run in the chamber 13, thereby significantly increasing the throughput of the substrate processing system 10.

Fig. 5 compares measured particle count in a CVD system that does not have heat shields 91 for the nozzles and a CVD system having nozzles 39 and surrounding heat shields 91. The CVD system 10 is similar to the one shown in Figs. 1

and 2, and the heat shields 91 of Figs. 4a, b are placed on the nozzles 39A, 39B disposed around the periphery of the substrate 17. The particles included in the plot are greater than about 0.16 μm in size. The process involves gapfill of a shallow trench isolation (STI) on a 300 mm silicon substrate 17 having a trench width of about 110 nm and an aspect ratio of about 4:1 by depositing a USG layer from SiH_4, H_2, and O_2. The pressure in the chamber 13 is about 4 mTorr.

The first three experiments were conducted without the heat shield 91. The source power levels for the top SRF generator (31A) and the side SRF generator (31B) are about 6 kW and 4 kW for the first test, about 7 kW and 4 kW for the second test, and about 7 kW and 5 kW for the third test. As shown in Fig. 5, the particle counts climb rapidly after about 80 seconds at rates that range from about 50 to about 116 particles per second. The other two experiments were conducted with the heat shield 91. The particles increase at a substantially lower rate when the heat shield 91 is used. The two tests employ top and side SRF power levels of about 6 kW and 4 kW, and about 7 kW and 5 kW, respectively. The rates of particle count increase for the two tests, respectively, are about 1 and about 5 particles per second after about 80 seconds, and are about 5 and about 9 particles per second after about 120 seconds.

It is to be understood that the above description is intended to be illustrative and not restrictive. Many embodiments will be apparent to those of skill in the art upon reviewing the above description. By way of example, the present invention may extend to other types of thermal as well as plasma deposition chambers and to other processes for processing substrates. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.